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Extended abstract

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CHARACTERISTICS OF THE INTERFACES IN A TURBULENT BOUNDARY LAYER

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Abstract Interfaces are commonly observed features of turbulent flows. Previous research has indicated the significance of these interfaces on the overall dynamics of the turbulent flow [1]. The current research focuses on both the external Turbulent/Non-Turbulent (T/NT) interface as well as internal layers that are present in an experimentally determined Turbulent Boundary Layer (TBL). Experiments are performed using planar Particle Image Velocimetry (PIV). First of all, attention is paid to the method of determining the interfaces. Furthermore, a quantitative comparison with jet data from [2] is made. Third, the properties of the internal interfaces are compared with the T/NT interface. Finally, the entrainment velocities of the interfaces are derived from the experimental results, which may be indicative of the growth rate of the TBL [1].

INTRODUCTION

Interfaces are frequently observed in turbulent flows. These interfaces are characterized by a velocity jump or a vorticity layer. Examples of such an interface is the T/NT interface. The turbulent flow field is surrounded by an irrotational non-turbulent fluid, separated by a sharp interface. Entrainment from the non-turbulent fluid towards turbulent occurs across this interface. In the jet case this entrainment process occurs predominantly via a small-scale nibbling process. To a lesser extent also large scale engulfment contributes to the entrainment [2–4]. More recently, similar behavior is shown in the TBL [5] . Besides the external interface bounding the T/NT flow fields, also internal vorticity layers are present in turbulent flows, which separate regions of approximately uniform momentum [6]. The growth of these regions can be viewed as entrainment processes analogous to jet growth resulting from the entrainment across the T/NT interface. However, only minor research has been paid to the dynamics and transport phenomena of these internal interfaces (see [1]). Moreover, much more attention has been given to interfaces in free shear flows, like jets, than to wall bounded shear flows.

Therefore, the aim of the current work is first of all to research the T/NT interface of a TBL and make a quantitative comparison with the jet case. Furthermore, the properties of the internal layers are compared with the external T/NT interface to see whether these layers have similar characteristics. Finally, the entrainment rate of the internal interfaces are obtained, which may be indicative of the growth rate.

EXPERIMENTAL MEASUREMENT SETUP

The turbulent boundary layer interfaces are investigated experimentally based on the flow velocity in the streamwise-wall-normal plane, which were obtained by planar PIV. The measurements were performed in the water channel at the Aero & Hydrodynamics laboratory of the TU Delft. The water tunnel has a square test section of 60x60 cm which is 5m in length. A uniform flow velocity up to 1 m/s can be achieved with a free-stream turbulence level less than 1%. A flat plate with a length of 4.4m was mounted 180mm above the bottom wall of the test section. A trip wire was added 60mm downstream of the leading edge to ensure that the boundary layer was turbulent in all measurements. Measurements were done 3.36m downstream the leading edge, resulting in a Re_θ=5164. The streamwise-wall normal plane, in which the u- and v-velocity components were measured, was illuminated with a 1mm thick laser sheet. The CCD camera (Image Pro LX 16M, LaVision) was equipped with a Micro-Nikkor f105mm objective, obtaining a field of view of 100x150mm^2, which guarantees that the complete TBL is captured at all time instances. The flow was seeded with 10 μm hollow glass spheres. Calibration and data acquisition and data post-processing was performed with a commercial software package (Davis 8.1, LaVision). In total 750 instantaneous velocity fields were captured at a frame rate of 0.77Hz. The spatial resolution of the velocity measurements is 6 viscous wall units. The properties of the boundary layer are summarized in Table 1.

U_e [m/s]	0.613	H [-]	1.35	δ^* [mm]	11.4	c_f [-]	$3.0\cdot10^{-3}$	res. [y^+]	6
δ_{95} [mm]	63.6	u_τ [mm/s]	23.9	θ [mm]	8.46	Re_θ [-]	5164		

Table 1. Boundary layer properties

RESULTS

A sample result is shown in Figure 1. The most appropriate detection criteria for the T/NT interface is the vorticity, as the interface separates irrotational non-turbulent fluid from vortical turbulent fluid [4]. Thresholding is applied in order to distinguish between genuine vorticity and experimental noise. The interface is determined according to method described by [7]. An example of a detected interface is shown in Figure 1a. Furthermore, Figure 1b,c show the normalized $\langle \Omega_Z \rangle$ and U profile over a vertical line in the vorticity field. The outer boundary is denoted with red dot. Figure 1b also reveals other distinct areas of vortical fluid indicating internal vorticity, which may be associated to layers when the streamwise velocity shows a step (Figure 1c). Conditional statistics over the T/NT interface are obtained as described by [2]. The conditional statistics over the T/NT interface are shown in Figure 2. As $\langle \Omega_Z \rangle \approx 0$

outside the BL, the interface is correctly identified. Furthermore, it is observed that the jump in $\langle \Omega_Z \rangle$ is qualitatively similar as in the jet case [2].
In our talk we first of all elaborate in more detail on the detection of the internal layers and discuss which parameters are suitable for detection of these layers. Second, the conditional statistics of these internal layers will be analyzed in order to study the characteristics like entrainment in both internal and external layers. Finally, a quantitative comparison with the jet data of [2] will be made.

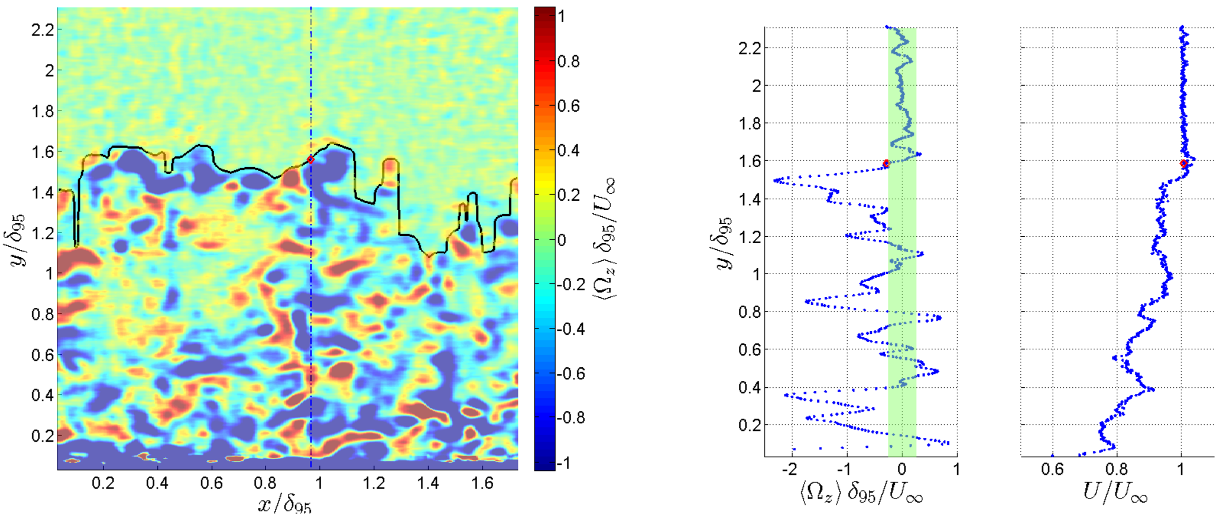

Figure 1. a) Detected T/NT interface based on thresholding of the vorticity (black line). The background color shows the out-of-plane vorticity Ω_z. b) The Ω_z profile along the dashed blue line (see a). The light green mask indicates the threshold value that is used to detect the T/NT interface. The detected interface location is marked with a red dot. c) The streamwise velocity component along the dashed blue line (see a)

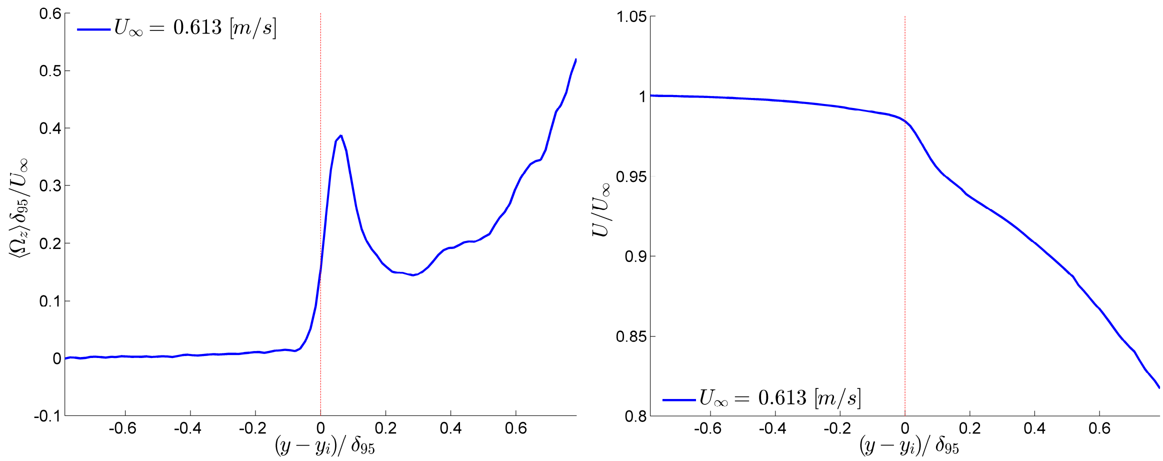

Figure 2. Conditional statistics over the T/NT interface, the vertical red dotted line denotes the position of the interface. a) The conditional out-of-plane vorticity jump. b) The conditional streamwise velocity component.

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